LHC SOFT PHYSICS AND TMD GLUON DENSITY AT SMALL X

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in collaboration with

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DESY, March 2014

OUTLINE

1. **Inclusive spectra of charge hadrons in p-p within soft QCD model including gluon**

2. **Gluon distribution in proton**

3. **Modified un-integrated gluon distribution**

4. **CCFM-evolution and structure functions**

5. **Summary**

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So, the inclusive spectrum is presented in the following form:

$$\rho\left(x=0,p_t\right)=\rho_q\left(x=0,p_t\right)+\rho_g\left(x=0,p_t\right)$$

Here

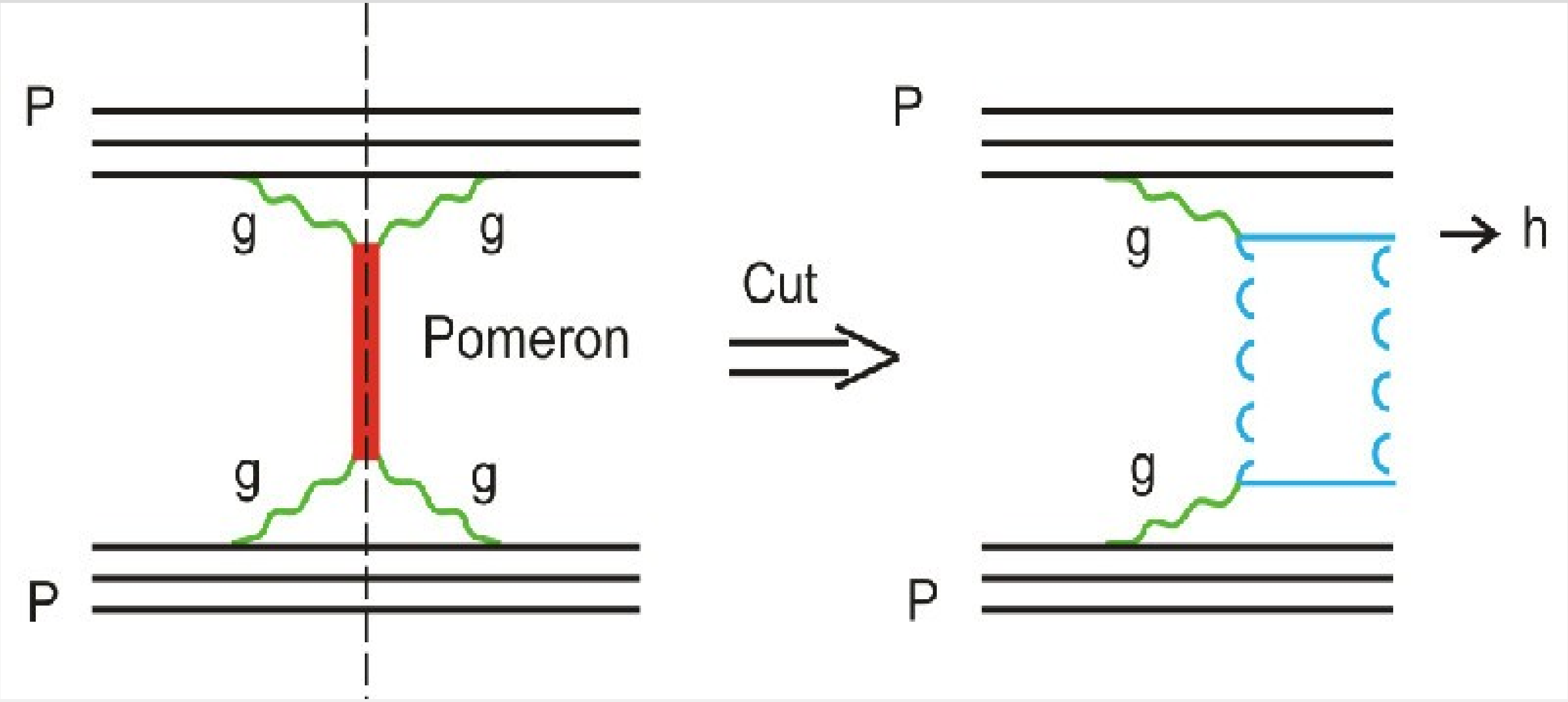
$$\rho_q = g\left(\frac{s}{s_0}\right)^{\Delta}\varphi_q;\ \varphi_q(0,p_t) = A_q\exp\left(-b_q p_t\right)$$

$$\rho_g = g\left[\left(\frac{s}{s_0}\right)^{\Delta} - \sigma_{nd}\right]\varphi_g;\ \varphi_g(0,p_t) = \sqrt{p_t}\,A_g\exp\left(-b_g p_t\right)$$

$A_q = 11.91 \pm 0.39,\ b_q = 7.29 \pm 0.11$ $g \approx 21$ mb

$A_g = 3.76 \pm 0.13\quad b_g = 3.51 \pm 0.02$ $\Delta \approx 0.12$

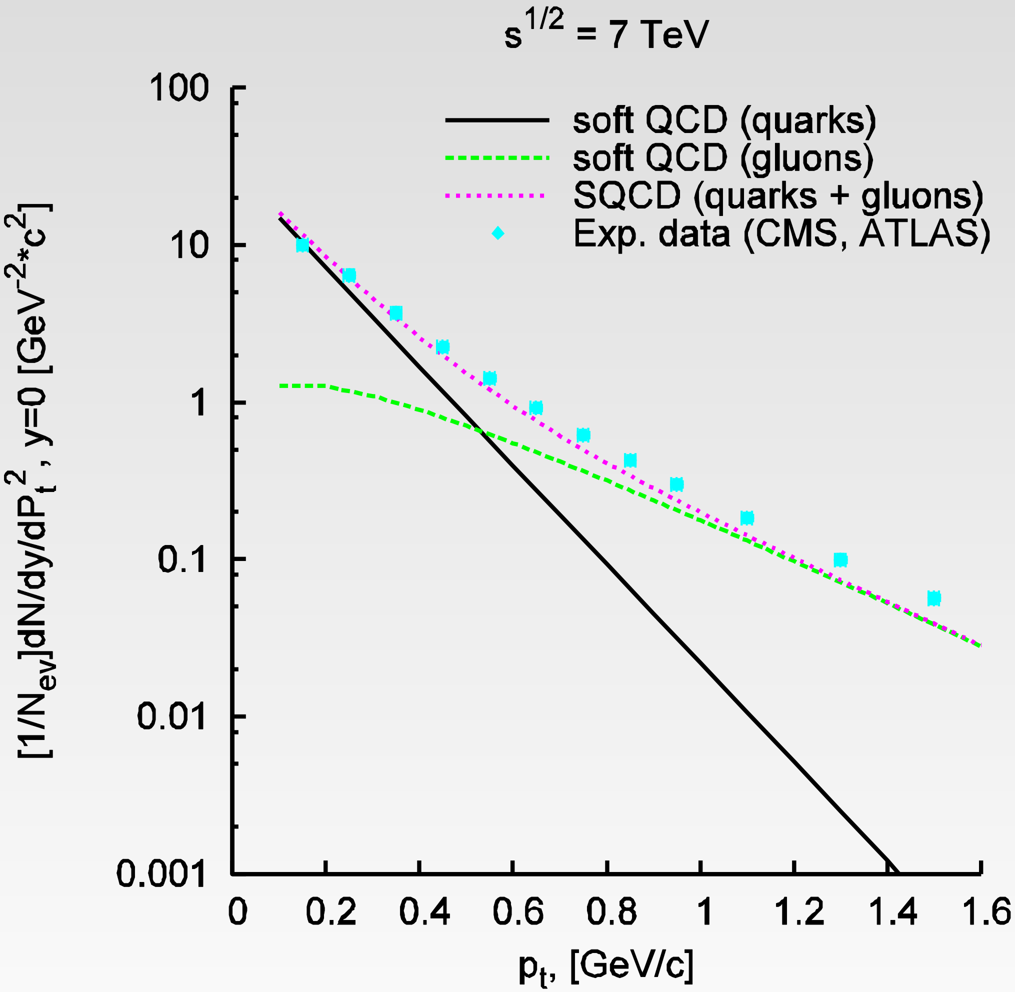
V.A. Bednyakov, A.V. Grinyuk, G.L., M. Poghosyan, Int. J.Mod.Phys. A 27 (2012) 1250012. hep-ph/11040532 (2011); hep-ph/1109.1469 (2011); Nucl.Phys. B 219 (2011) 225.



One-Pomeron exchange (left) and the cut one-Pomeron exchange (right); P-proton, g-gluon, h-hadron produced in PP

In the light cone dynamics the proton has a general decomposition:

$|uud\rangle, |uudg\rangle, |uudq\bar{q}\rangle, ...$ S.J.Brodsky, C.Peterson, N.Sakai, Phys.Rev. D 23 (1981) 2745.



s^1/2 = 7 TeV
100
10
1
0.1
0.01
0.001
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
soft QCD (quarks)
soft QCD (gluons)
SQCD (quarks + gluons)
Exp. data (CMS, ATLAS)
[1/Nev]dN/dy/dPt^2, y=0 [GeV^-2*c^2]
pt, [GeV/c]

The cut one-pomeron exchange

$$\rho(x, p_{ht}) = F(x_+, p_{ht})\, F(x_-, p_{ht})$$

Here

$$F(x_+, p_{ht}) = \int dx_1 \int d^2 k_{1t}\, f_q(x_1, k_{1t})\, G_q^h\left(\frac{x_+}{x_1}, p_{ht} - k_{1t}\right)$$

where

$$G_q^h(z, k_t) = z D_q^h(z, k_t) \qquad f_q = g \otimes P_{g-q\bar{q}}$$

where $P_{g-q\bar{q}}$ is the splitting function of a gluon to the quark-antiquark pair

A.A.Grinyuk, A.V.Lipatov, G.L., N/P/Zotov, Phys.Rev. D87, 074017 (2013).

UN-INTEGRATED GLUON DISTRIBUTION IN PROTON

$$xA\left(x,k_t^2,Q_0^2\right)=\frac{3\sigma_0}{4\pi^2\alpha_s}R_0^2\left(x\right)k_t^2\exp\left(-R_0^2\left(x\right)k_t^2\right) \quad ,$$

where $R_0=C_1(x/x_0)^{\lambda/2}$, $C_1=1/\text{GeV}$

K.Golec-Biernat & M.Wuesthoff, Phys.Rev. D60, 114023 (1999); Phys.Rev. D59, 014017 (1998)

H.Jung, hep-ph/0411287, Proc. DIS'2004 Strbske Pleco, Slovakia

$$xg(x,k_t,Q_0) = C_0 C_3 (1-x)^{b_g} \left(R_0^2(x) k_t^2 + C_2 (R_0(x) k_t)^a \right)$$

$$\exp\left(-R_0(x) k_t - d (R_0(x) k_t)^3 \right) ,$$

where $C_0 = 3\sigma_0 / (4\pi^2 \alpha_s(Q_0^2))$

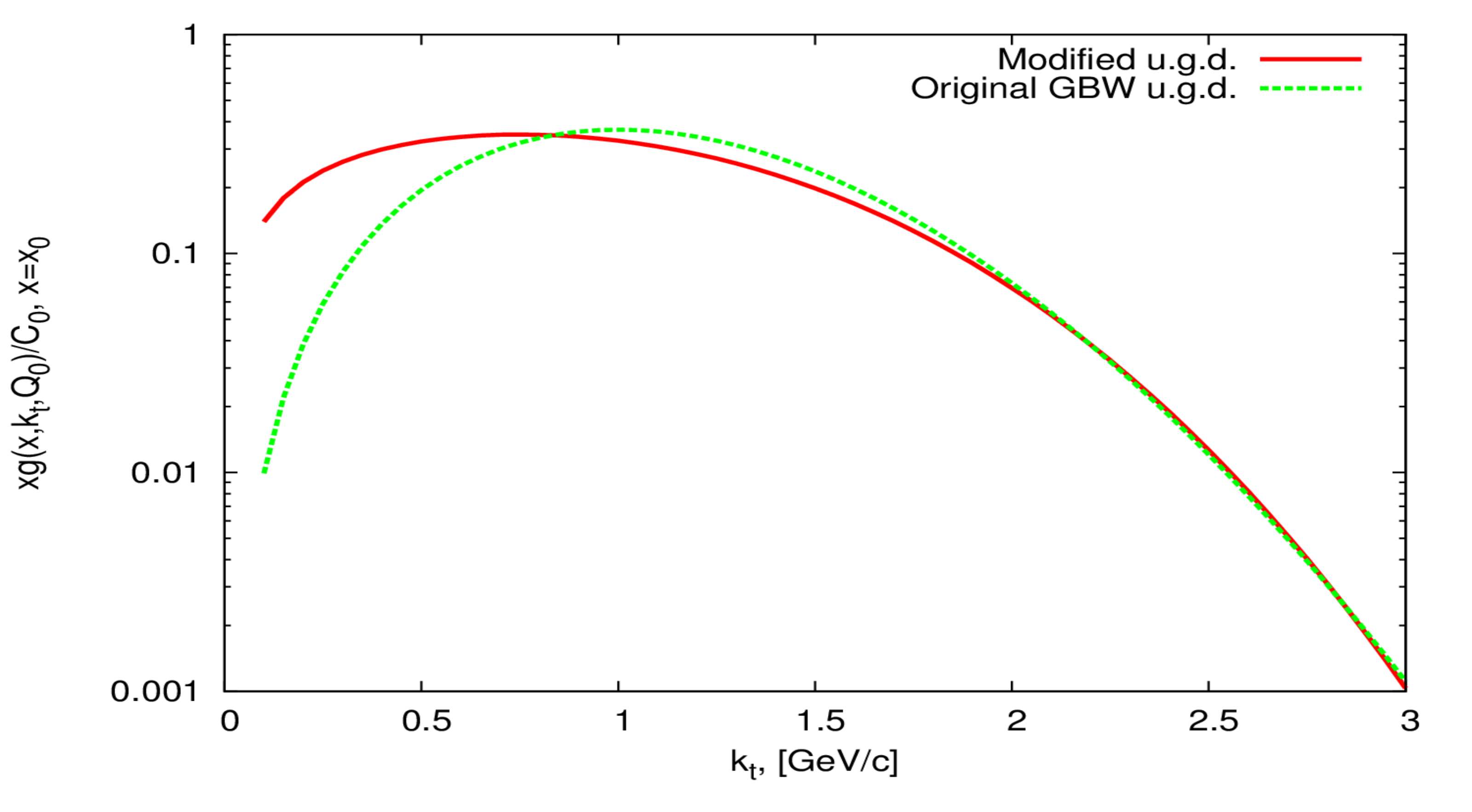
The coefficient C_3 is found from the relation

$$xg(x,Q_0^2) = \int_0^{Q_0^2} xg(x,k_t^2,Q_0^2) dk_t^2$$

A.Grinyuk, H.Jung, G.L., A.Lipatov, N.Zotov, hep-ph/1203.0939; Proc.MPI-11, DESY, Hamburg, 2012.

At $k_t -> 0$ our UGD goes to zero as k_t^a where $a < 1$

It has been confirmed by B.I.Ermolaev, V.Greco, S.I.Troyan, Eur.Phys.J. C 72 (2012) 1253; hep-ph/1112.1854.



Green line is the GBW u.g.d. K. Golec-Biernat & M. Wuesthoff, Phys.Rev.D60, 114023 (1999).Red line is the modified u.g.d. A.Grinyuk, H.Jung, G.L., A.Lipatov, N.Zotov, hep-ph/1203.0939; Proc.MPI-11, DESY, Hamburg, 2012; A.A.Grinyuk, A.V.Lipatov, G.L., N.P.Zotov, Phys.Rev. D87, 074017 (2013); hep-ph/1301.4545.

CCFM evolution equation

$$f_g(x,k_T^2,\bar{q}^2) = f_g^0(x,k_T^2,Q_0^2)\Delta_s(\bar{q}^2,Q_0^2) + \int\frac{dz}{z}\int\frac{dq^2}{q^2}\times$$

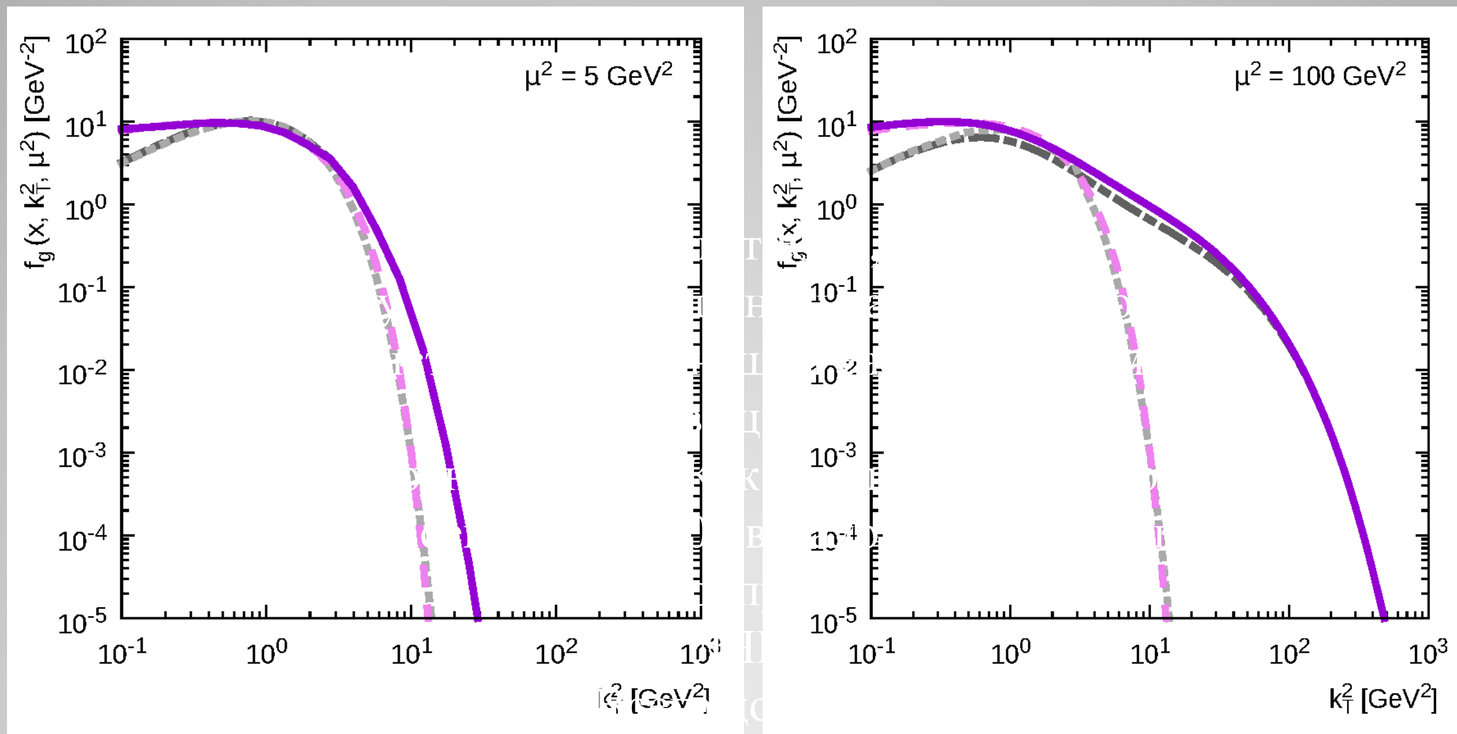
$$\theta(\bar{q}-zq)\Delta_s(\bar{q}^2,q^2)P_{gq\bar{q}}(z,q^2,k_T^2)f_g\left(\frac{x}{z},k_T'^2,q^2\right)$$

Here $k_T' = q(1-z)/z + k_T$ and the Sudakov form factor $\Delta_s(q_1^2,q_2^2)$ describes the probability of no radiation between q_2 and q_1, $P_{gq\bar{q}}$ is the splitting function, f_g is the gluon density.

The first term means the contribution of non resolvable branchings between the starting scale Q_0 and the factorization scale $\bar{q}$.

A.V.Lipatov, G.L., N.P.Zotov, hep-ph/1310.7893.

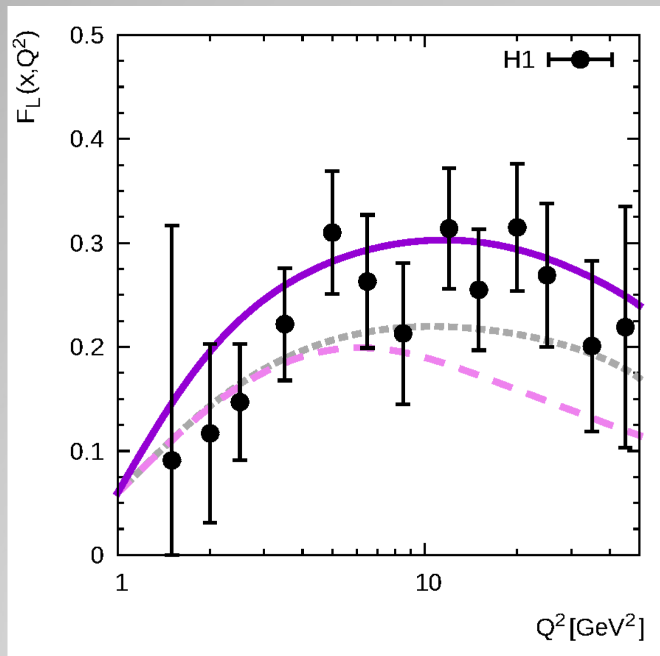
Gluon distribution as a function of k_T^2 at $x = 10^{-4}$

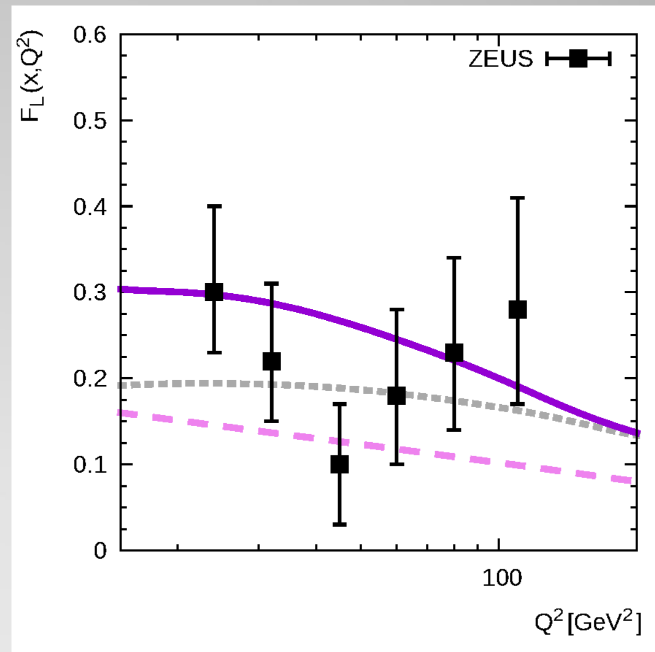


The solid curves correspond to the CCFM-evolved gluon density, the dashed lines mean the contribution of initial our gluon distribution; the dash-dotted and dotted curves correspond to the CCFM-evolved GBW gluon density and the pure (non-evolved) GBW one, respectively.

A.V.Lipatov, G.L., N.P.Zotov, PRD 89, 014001 (2014); hep-ph/1301.4545.

Longitudinal structure function

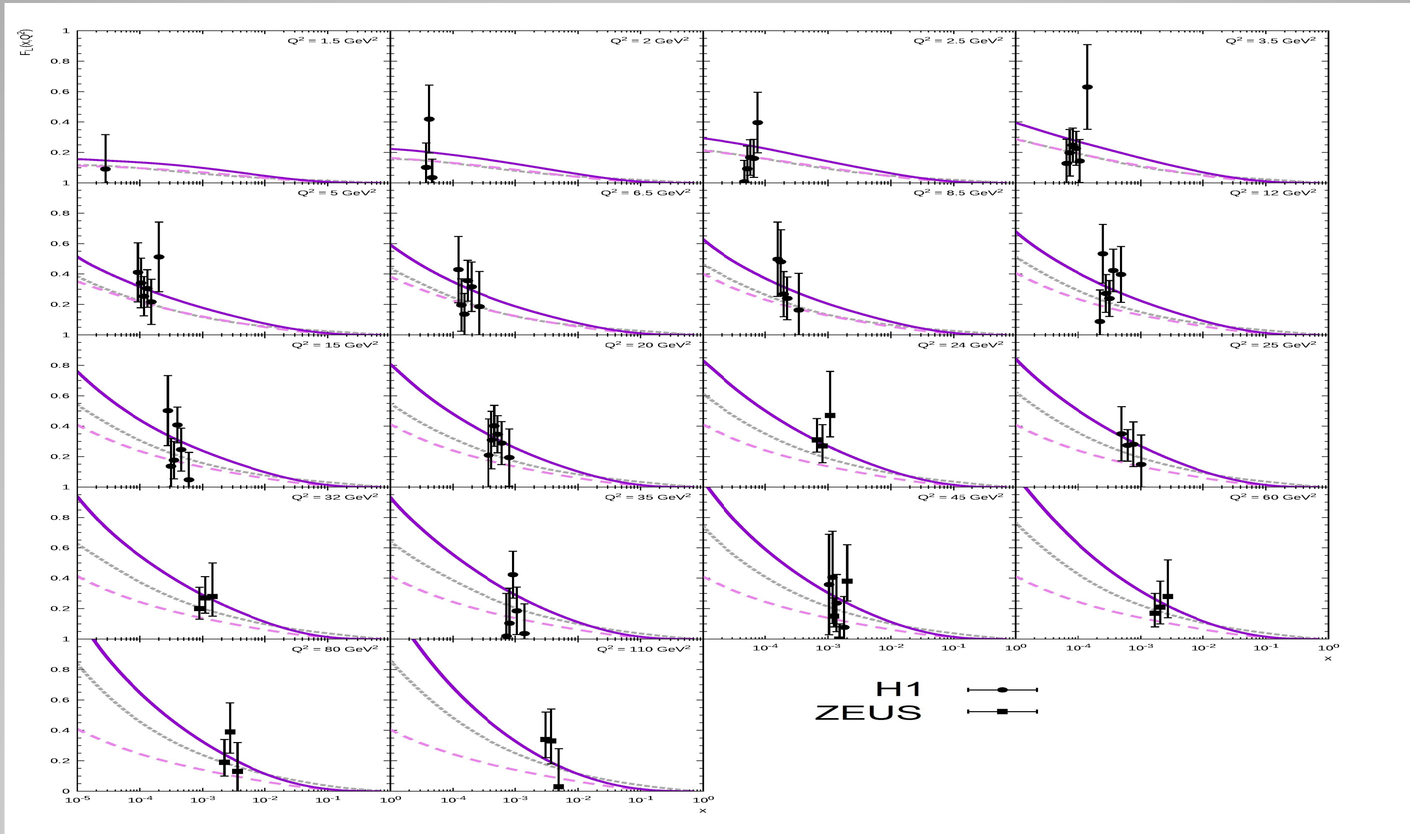




The solid lines correspond to the proposed CCFM – evolved TMD gluon density; the dashed curves mean the contribution from the our non evolved gluon density; the dottet lines correspond to the CCFM-evolved GBW g.d. For ZEUS Q^2/s is a constant for each bin, which corresponds to $y = Q^2/xs = 0.71$ where $\sqrt{s} = 225$ GeV.

A.V.Lipatov, G.L., N.P.Zotov, PRD 89, 014001 (2014); hep-ph/1301.4545.

Longitudinal structure function as a function of x



The solid lines correspond to the proposed CCFM – evolved TMD gluon density; the dashed curves mean the contribution from the our non evolved gluon density; the dottet lines correspond to the CCFM-evolved GBW g.d

A.V.Lipatov, G.L., N.P.Zotov, PRD 89, 014001 (2014); hep-ph/1301.4545.

DESY, March 2014

SUMMARY

1.The TMD gluon density is proposed at initial $Q_0^2 = 1(GeV/c)^2$ and their parameters are verified by the description of the LHC data on the hadron spectra in the soft kinematical region.

2. The CCFM evolution equation was solved using the proposed TMD g.d. at starting Q_0^2 .

3. The CCFM-evolved u.g.d. results in a satisfactory description of the H1 and ZEUS data on the longitudinal structure function $F_L(x, Q^2)$.

4. The proposed u.g.d. is different from the GBW one at $k_T < 1 GeV/c$ and at any Q^2 values by a factor of one order.

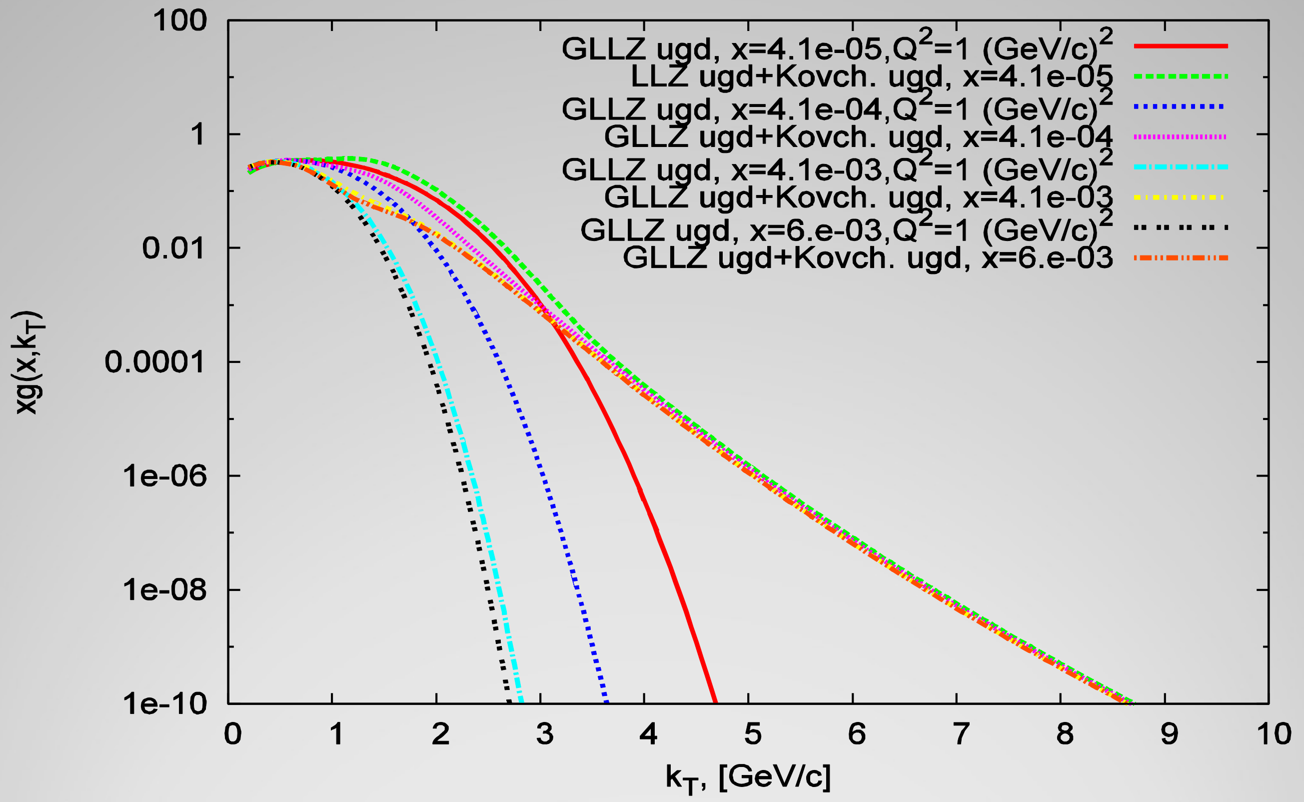
5. The link between soft processes at the LHC and small x-physics at HERA , pointed early for small Q^2 , is confirmed and extended to a wide kinematical region .

6.The proposed TMD gluon density as well as the GBW one is due to the saturation of the gluon density at small Q^2 , scale of which can be verified by the description of both the LHC soft data and the HERA low-x data.

DESY, March 2014

THANK YOU VERY MUCH FOR YOUR ATTENTION !

New ugd combined GLLZ ugd and Kovchegov ugd



Kt-factorization

Photo-production cross section

$$\sigma = \int \frac{dz}{z} d^2 k_t \, \sigma_{part}\left(\frac{x}{z}, k_t^2\right) F\left(z, k_t^2\right)$$

Here $F\left(z, k_t^2\right)$ is the un-integrated parton density function, $\sigma_{part}\left(x/z, k_t^2\right)$ is the partonic cross section.

Classification scheme:

$xF\left(x, k_t^2\right)$ is used by BFKL

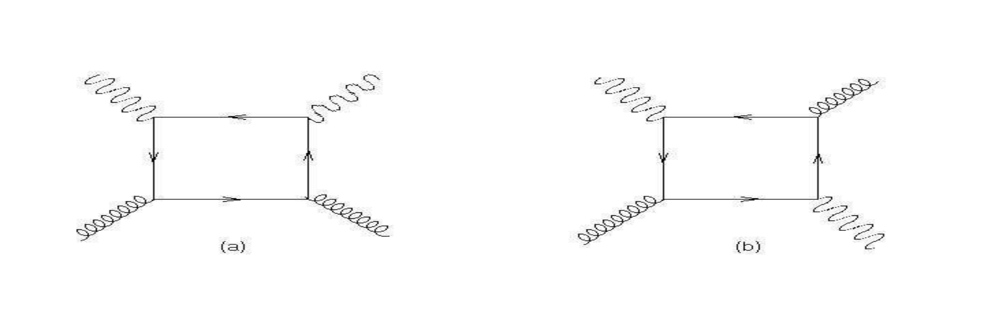
$xA\left(x, k_t^2, \bar{Q}^2\right)$ describes the CCFM type UGD with an additional factorization scale $\bar{Q}$ (such as $\alpha_s\left(\bar{Q}^2\right) \leq 1$)

$xG\left(x, k_t^2\right)$ describes the DGLAP type UGD

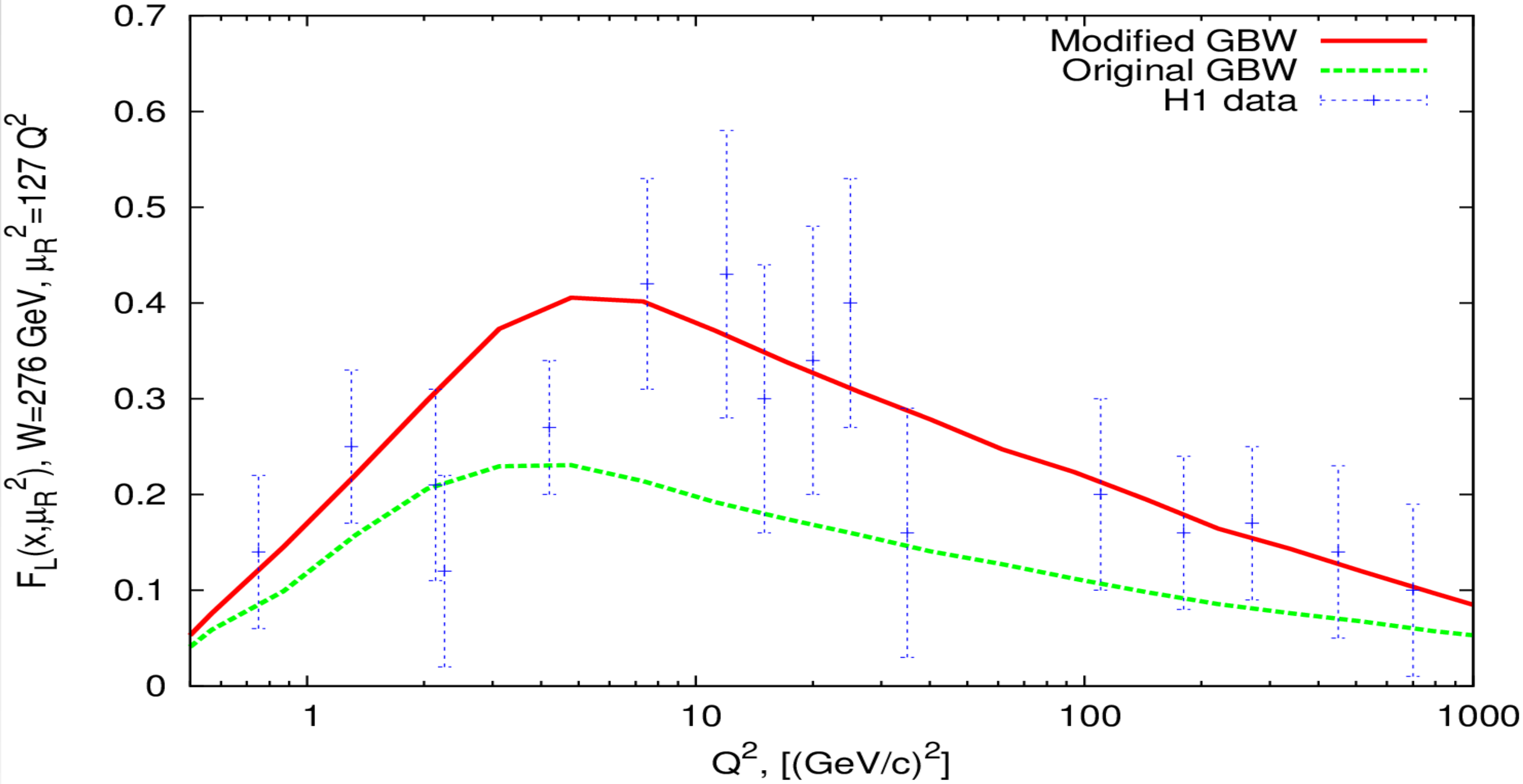
Longitudinal structure function within the kt-factorization

$$F_L(x,Q^2) = \int_x^1 \frac{dz}{z} \int_0^{Q^2} dk_t^2 \sum_{i=u,d,s} e_i^2 C_L^g\left(\frac{x}{z}, Q^2, m_i^2, k_t^2\right) \phi_g(z,k_t^2),$$

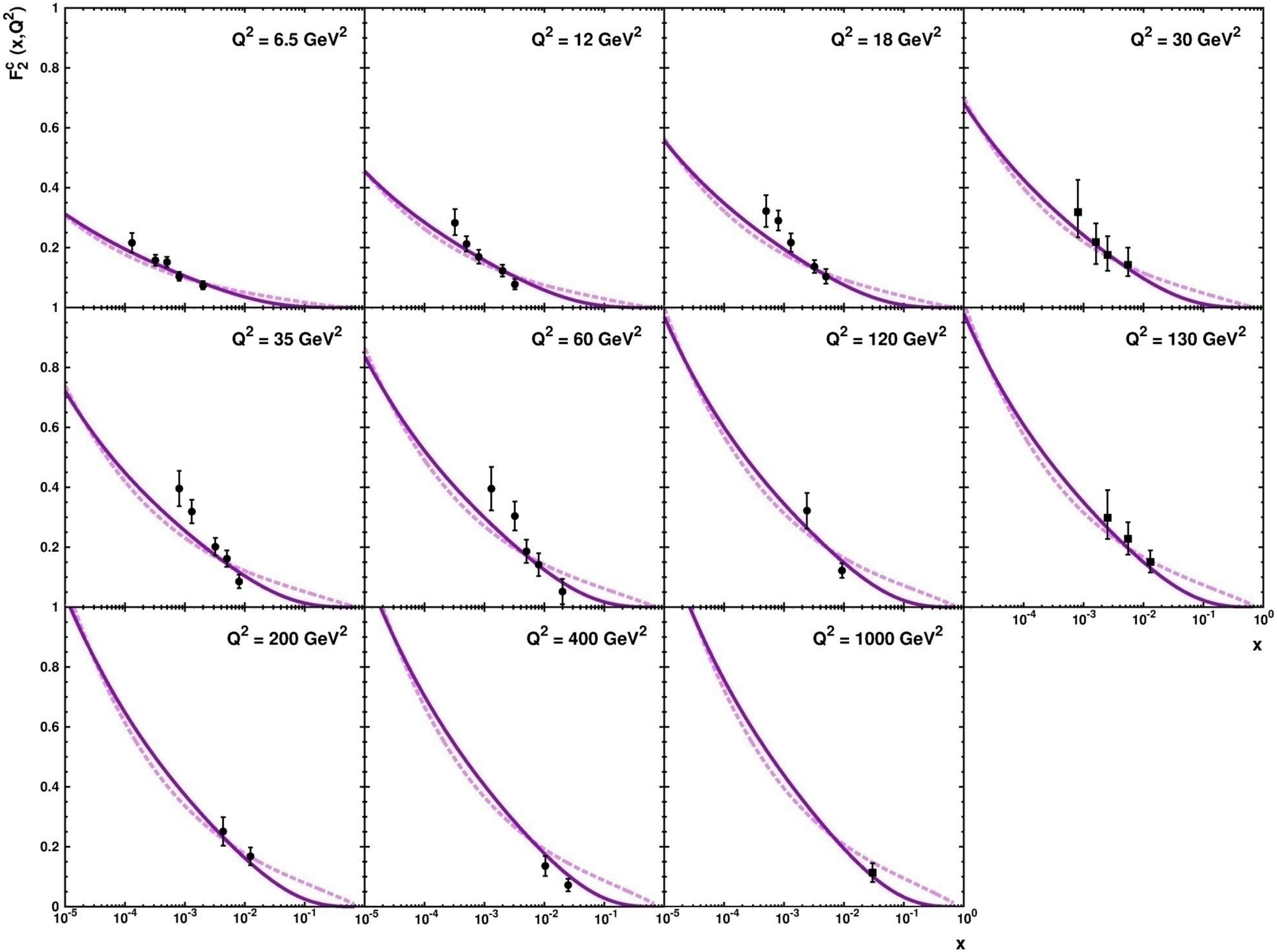
$$\phi_g(x,k_t^2) = xg(x,k_t^2), \quad xg(x,Q^2) = xg(x,Q_0^2) + \int_{Q_0^2}^{Q^2} dk_t^2 \phi_g(x,k_t^2)$$



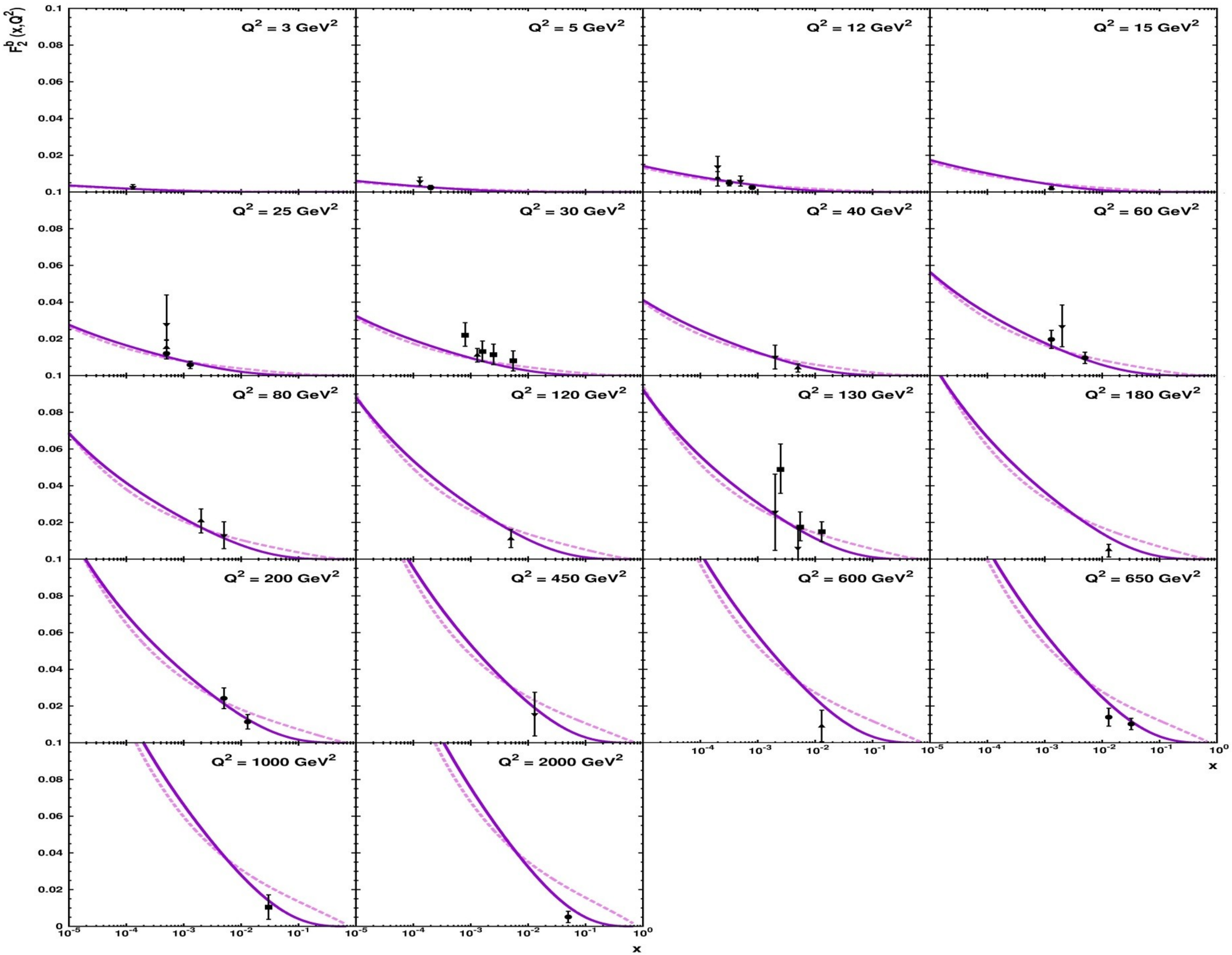
A.V. Kotikov, A.V. Lipatov, N.P. Zotov, Eur.Phys.J., C27 92003)219.
H. Jung, A.V. Kotikov, A.V. Lipatov, N.P. Zotov, DIS 2007, hep-ph/07063793.



F_L as a function of Q^2 at W=276 GeV and $\mu_R^2 = 127\, Q^2$

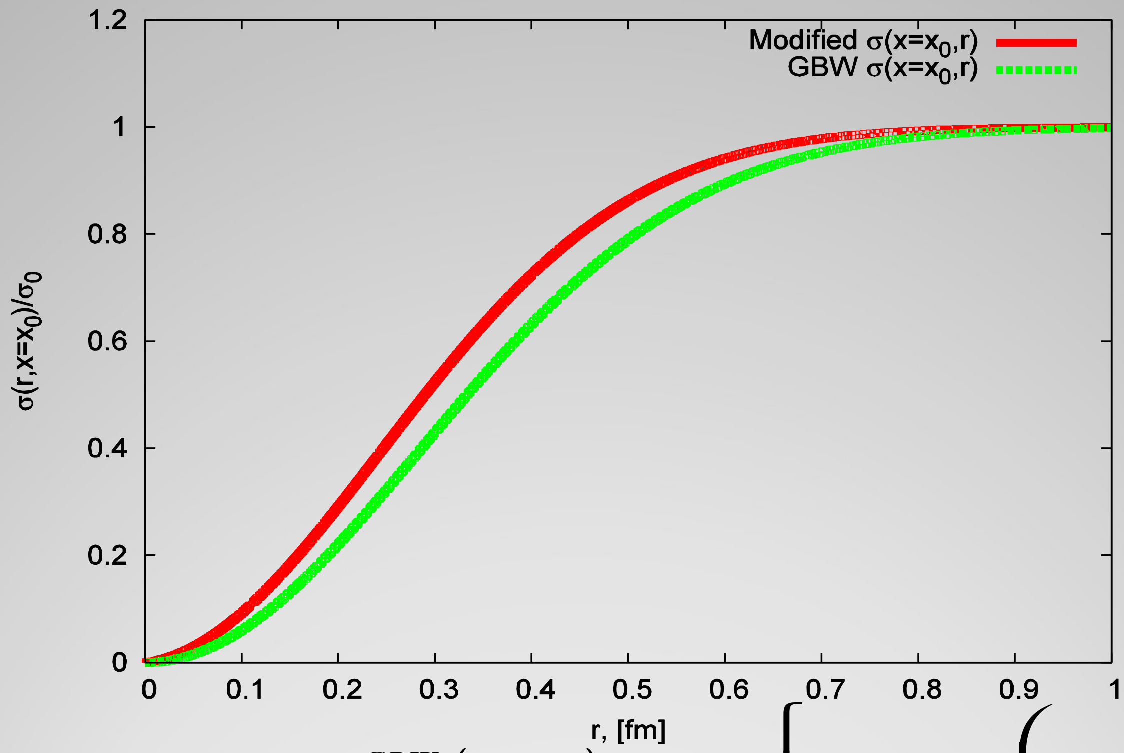


$F_2^c(x,Q^2)$
Q^2 = 6.5 GeV^2
Q^2 = 12 GeV^2
Q^2 = 18 GeV^2
Q^2 = 30 GeV^2
Q^2 = 35 GeV^2
Q^2 = 60 GeV^2
Q^2 = 120 GeV^2
Q^2 = 130 GeV^2
Q^2 = 200 GeV^2
Q^2 = 400 GeV^2
Q^2 = 1000 GeV^2
x



$F_2^b(x,Q^2)$
$Q^2 = 3\ GeV^2$
$Q^2 = 5\ GeV^2$
$Q^2 = 12\ GeV^2$
$Q^2 = 15\ GeV^2$
$Q^2 = 25\ GeV^2$
$Q^2 = 30\ GeV^2$
$Q^2 = 40\ GeV^2$
$Q^2 = 60\ GeV^2$
$Q^2 = 80\ GeV^2$
$Q^2 = 120\ GeV^2$
$Q^2 = 130\ GeV^2$
$Q^2 = 180\ GeV^2$
$Q^2 = 200\ GeV^2$
$Q^2 = 450\ GeV^2$
$Q^2 = 600\ GeV^2$
$Q^2 = 650\ GeV^2$
$Q^2 = 1000\ GeV^2$
$Q^2 = 2000\ GeV^2$
x

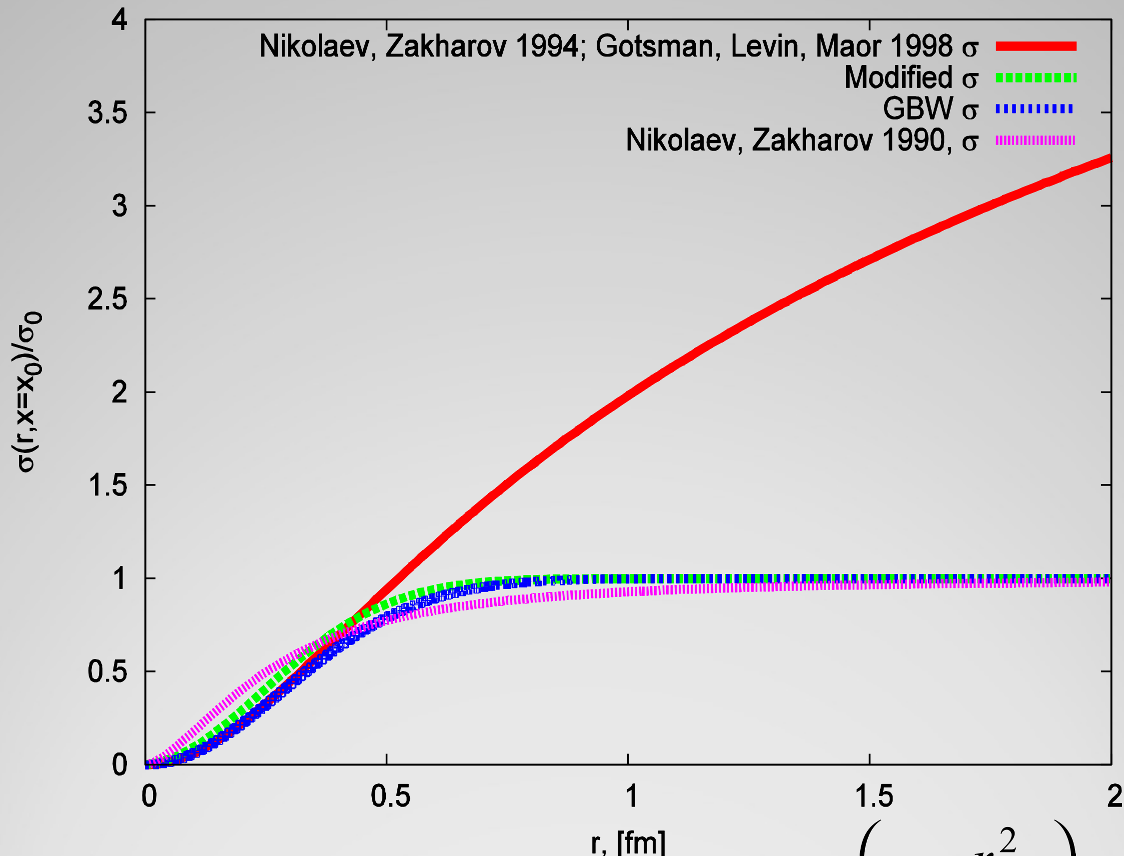
Effective dipole cross section



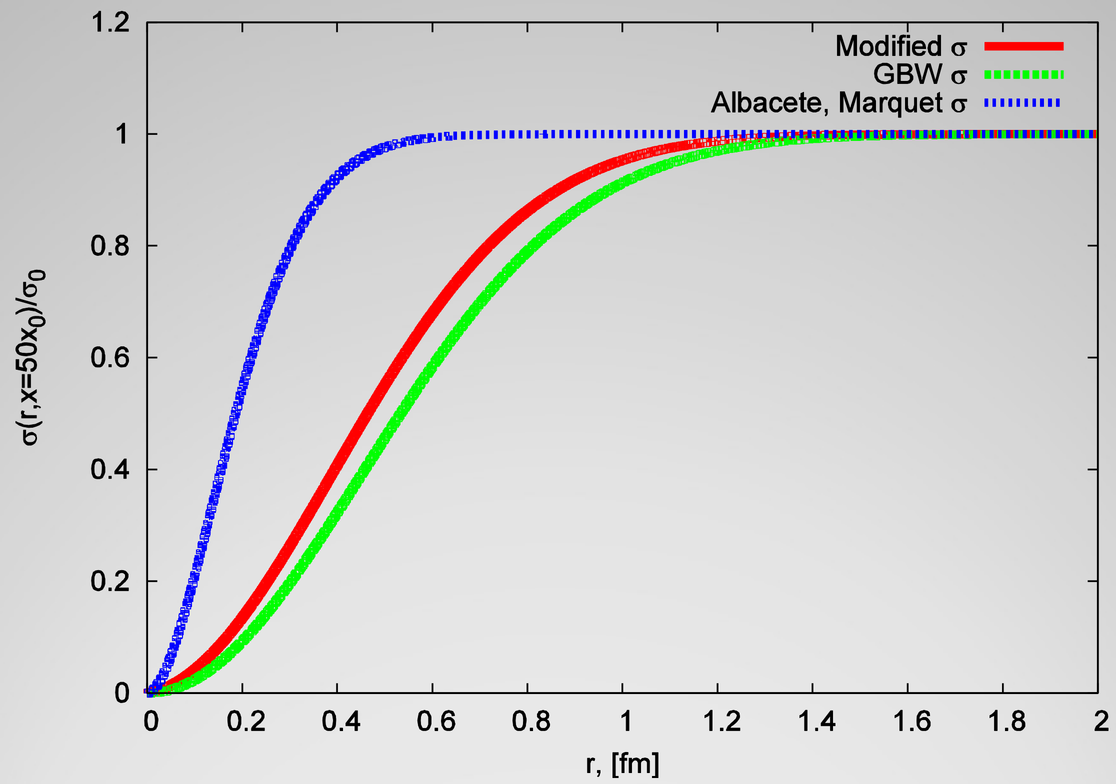
Green line: $$\sigma_{dipole}^{GBW}(x,r)=\sigma_0\left\{1-\exp\left(-\frac{r^2}{4R_0^2(x)}\right)\right\}$$

Red line: $$\sigma_{dipole}^{GBW}(x,r)=\sigma_0\left\{1-\exp\left(-\frac{a_1 r}{R_0(x)}-\frac{a_2 r^2}{R_0^2(x)}\right)\right\}$$

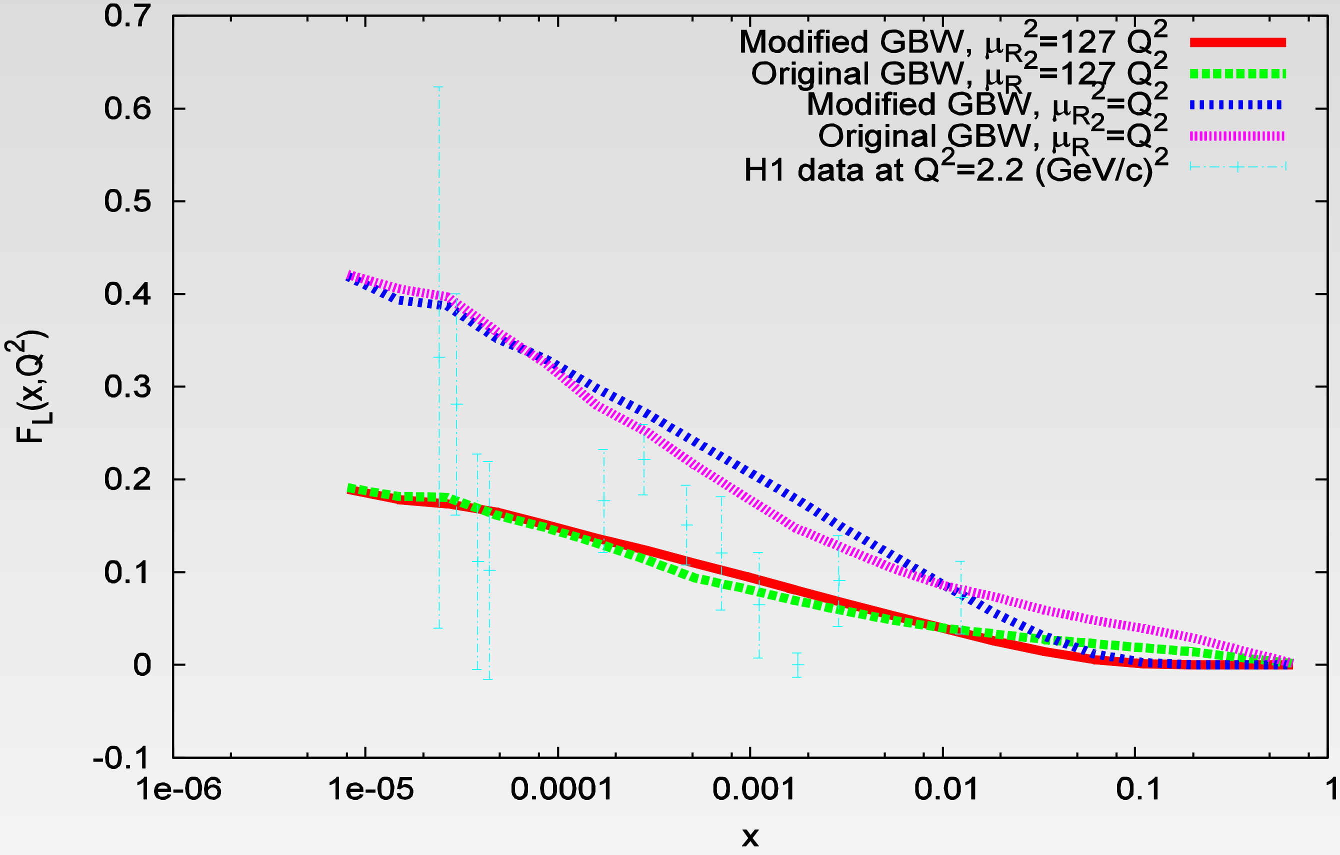
Effective dipole cross section



Red line corresponds to $\sigma_{dipole} = \sigma_0 \ln\left(1 + \frac{r^2}{4R_0^2}\right)$

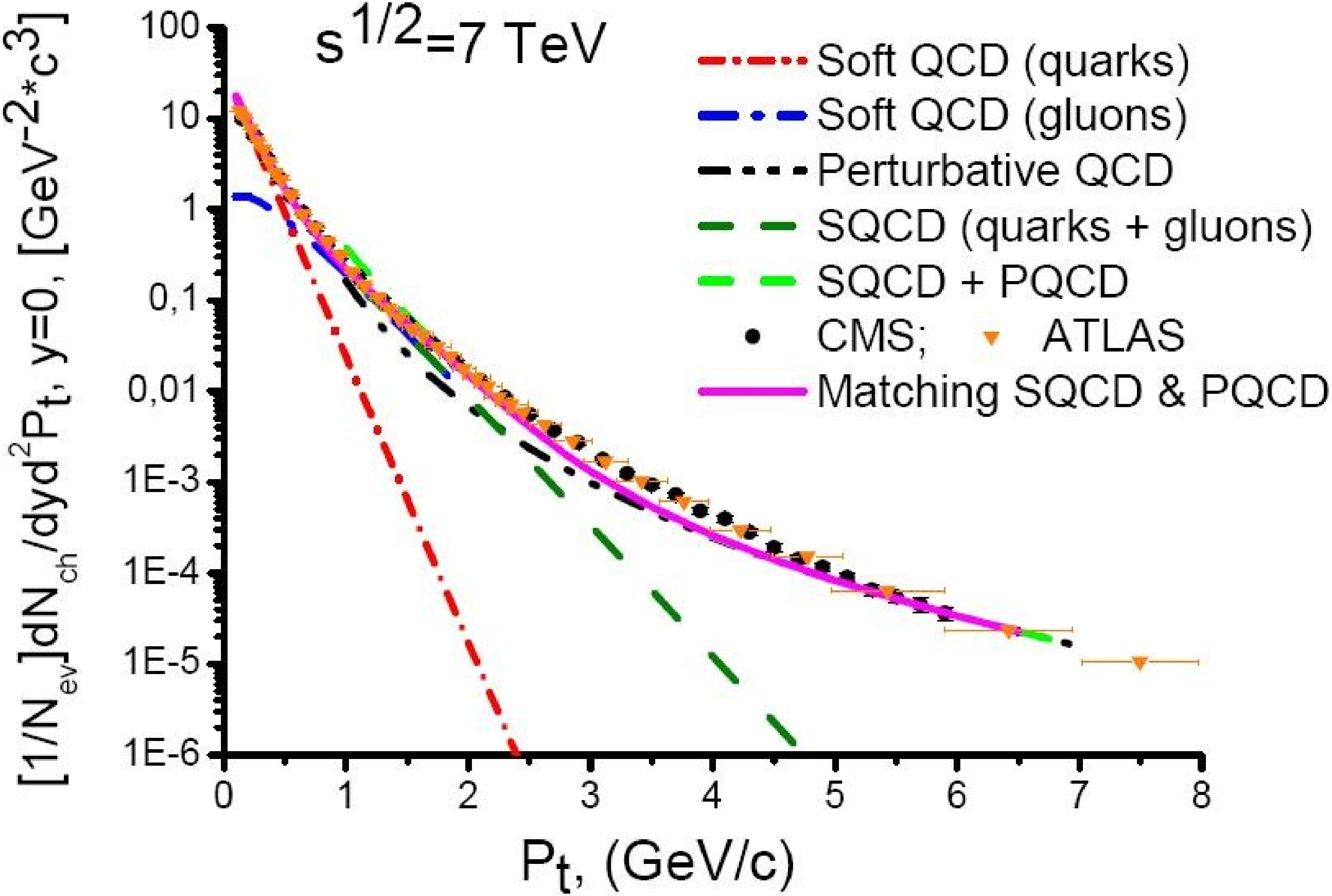


Modified σ
GBW σ
Albacete, Marquet σ
σ(r,x=50x0)/σ0
r, [fm]
1.2
1
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2



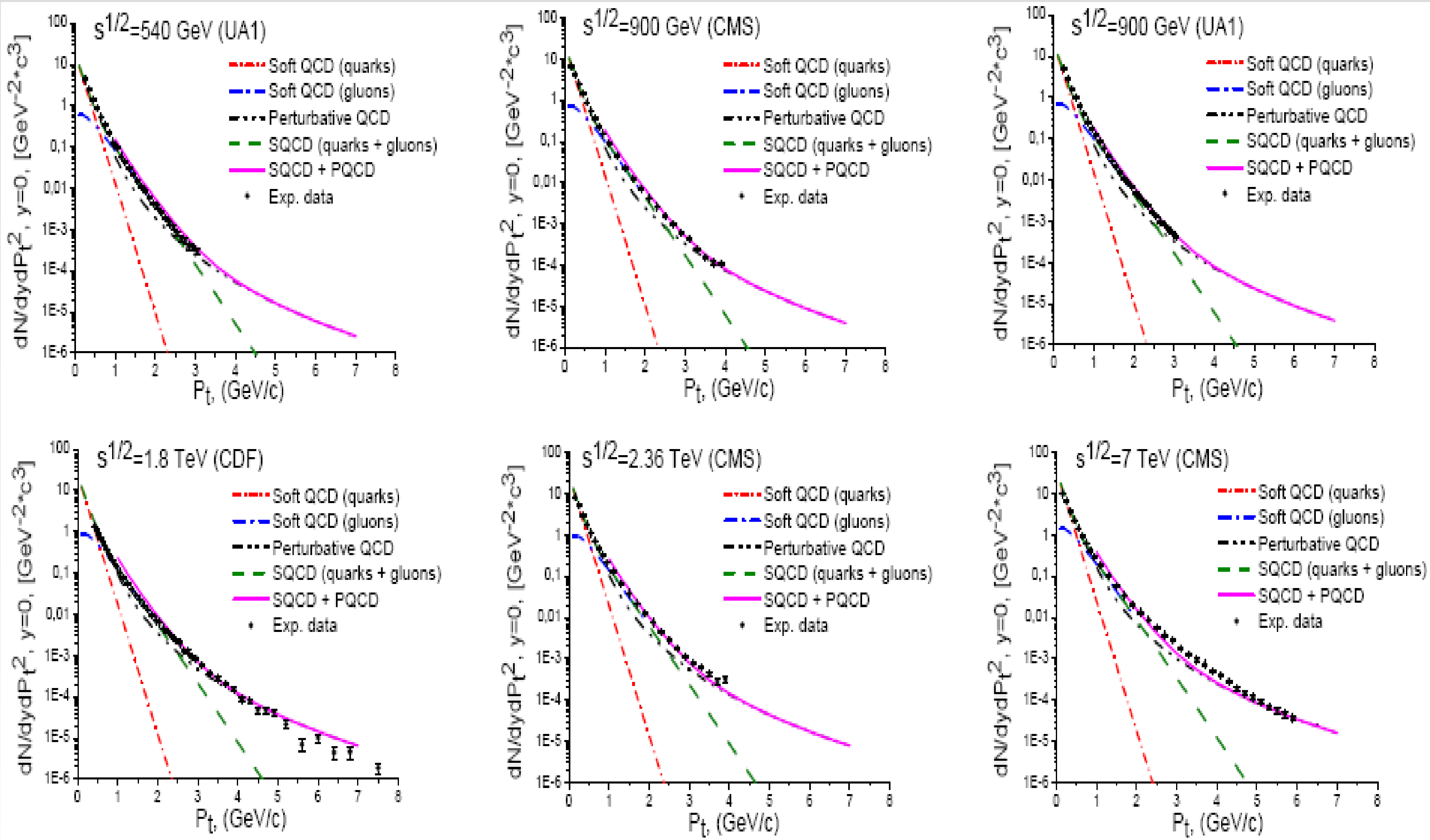
The x-dependence of F_L at $Q^2 = 2.2(GeV/c)^2$ assuming

$\mu_R^2 = KQ^2$ and $\mu_R^2 = Q^2$, where $K = 127$



s^{1/2}=7 TeV
Soft QCD (quarks)
Soft QCD (gluons)
Perturbative QCD
SQCD (quarks + gluons)
SQCD + PQCD
CMS; ATLAS
Matching SQCD & PQCD
[1/N_ev]dN_ch/dyd^2P_t, y=0, [GeV^-2*c^3]
P_t, (GeV/c)
100
10
1
0,1
0,01
1E-3
1E-4
1E-5
1E-6
0
1
2
3
4
5
6
7
8

2012



s1/2=540 GeV (UA1)
s1/2=900 GeV (CMS)
s1/2=900 GeV (UA1)
s1/2=1.8 TeV (CDF)
s1/2=2.36 TeV (CMS)
s1/2=7 TeV (CMS)
Soft QCD (quarks)
Soft QCD (gluons)
Perturbative QCD
SQCD (quarks + gluons)
SQCD + PQCD
Exp. data
dN/dydPt2, y=0, [GeV-2*c3]
Pt, (GeV/c)

Inclusive hadron production in central region and the AGK cancellation

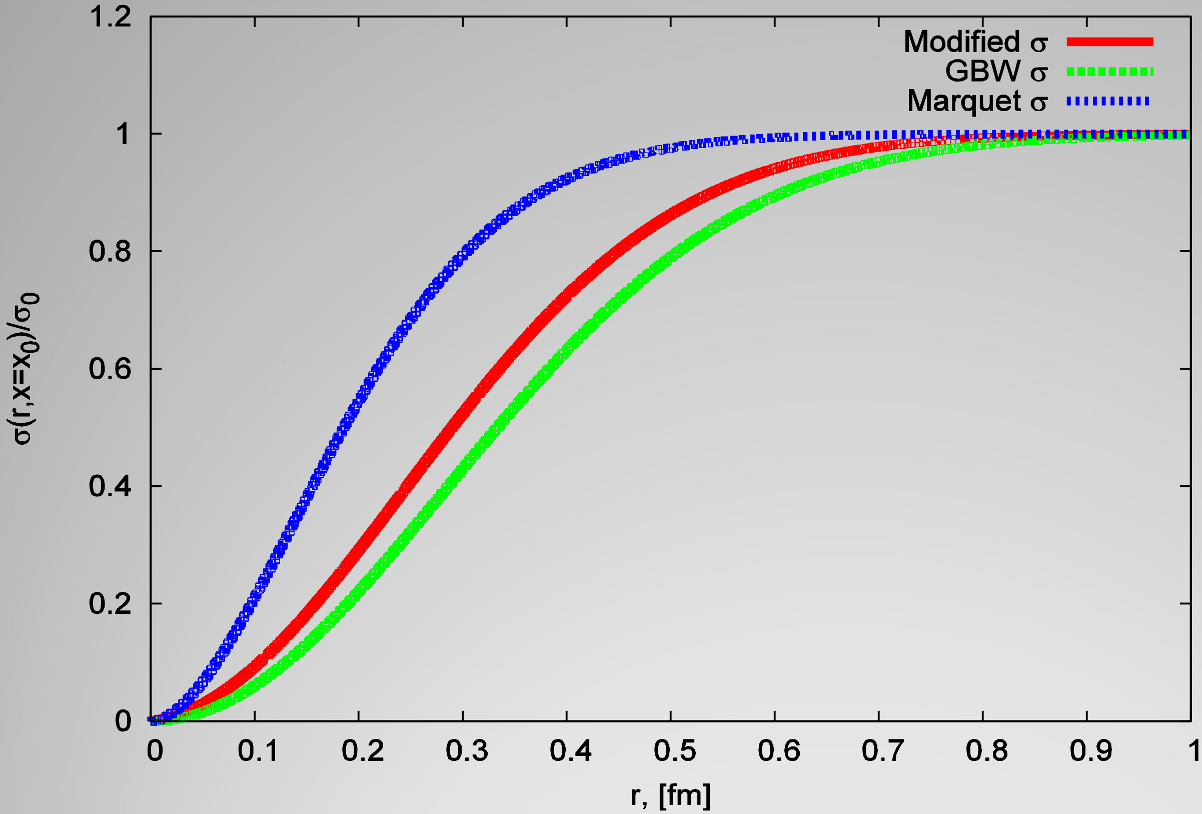
According to the AGK, the n-Pomeron contributions to the inclusive hadron spectrum at y=0 are cancelled and only the one-Pomeron contributes. This was proved asymptotically, i.e., at very high energies.

Using this AGK we estimate the inclusive spectrum of the charged hadrons produced in p-p at y=0 as a function of the transverse momentum including the quark and gluon components in the proton.

$$\rho_q(x=0,p_t)=\phi_q(0,p_t)\sum_{n=1}^{\infty} n\sigma_n(s)=gs^{\Delta}\phi_q(0,p_t)$$

$$\rho_g(x=0,p_t)=\varphi_g(0,p_t)\sum_{n=2}(n-1)\sigma_n(s)=$$

$$\varphi_g(0,p_t)(gs^{\Delta}-\sigma_{nd})$$



Javier L. Albacete, Cyrille Marquet, arXiv:1001.137 [hep-ph]

Blue line corresponds to

$$\sigma_{dipole}^{AM} = \sigma_0 \left\{ 1 - \exp\left[-\frac{r^2}{4R_0^2} \ln\left(\frac{1}{\Lambda r} + e \right) \right] \right\}; \Lambda = 0.24 GeV = 1.2\, fm^{-1}; R_0 = 1 GeV^{-1} = 0.2\, fm$$

Inclusive hadron production in central region and the AGK cancellation

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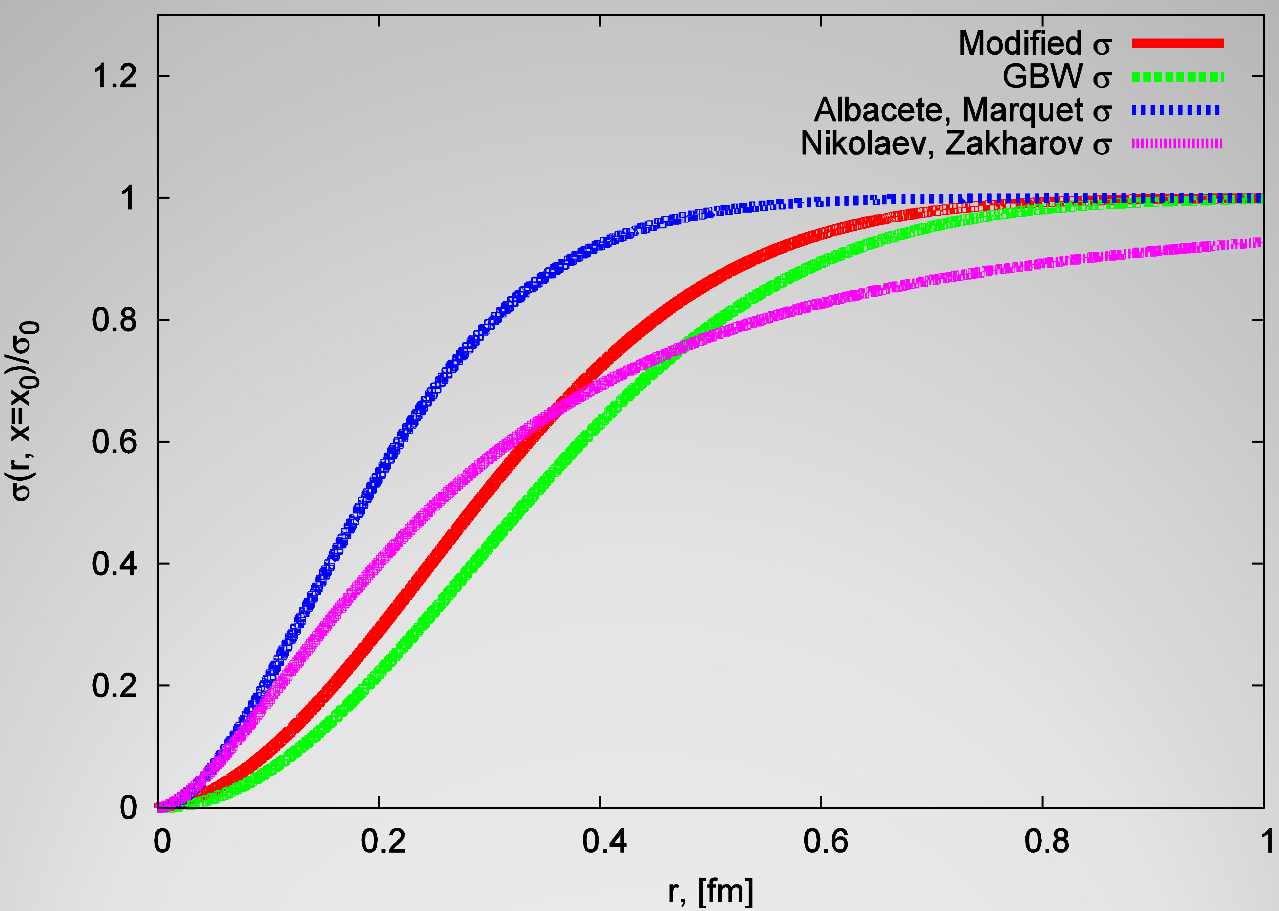
$$\rho_q(x=0,p_t)=\phi_q(0,p_t)\sum_{n=1}^{\infty} n\sigma_n(s) = gs^{\Delta}\phi_q(0,p_t)$$

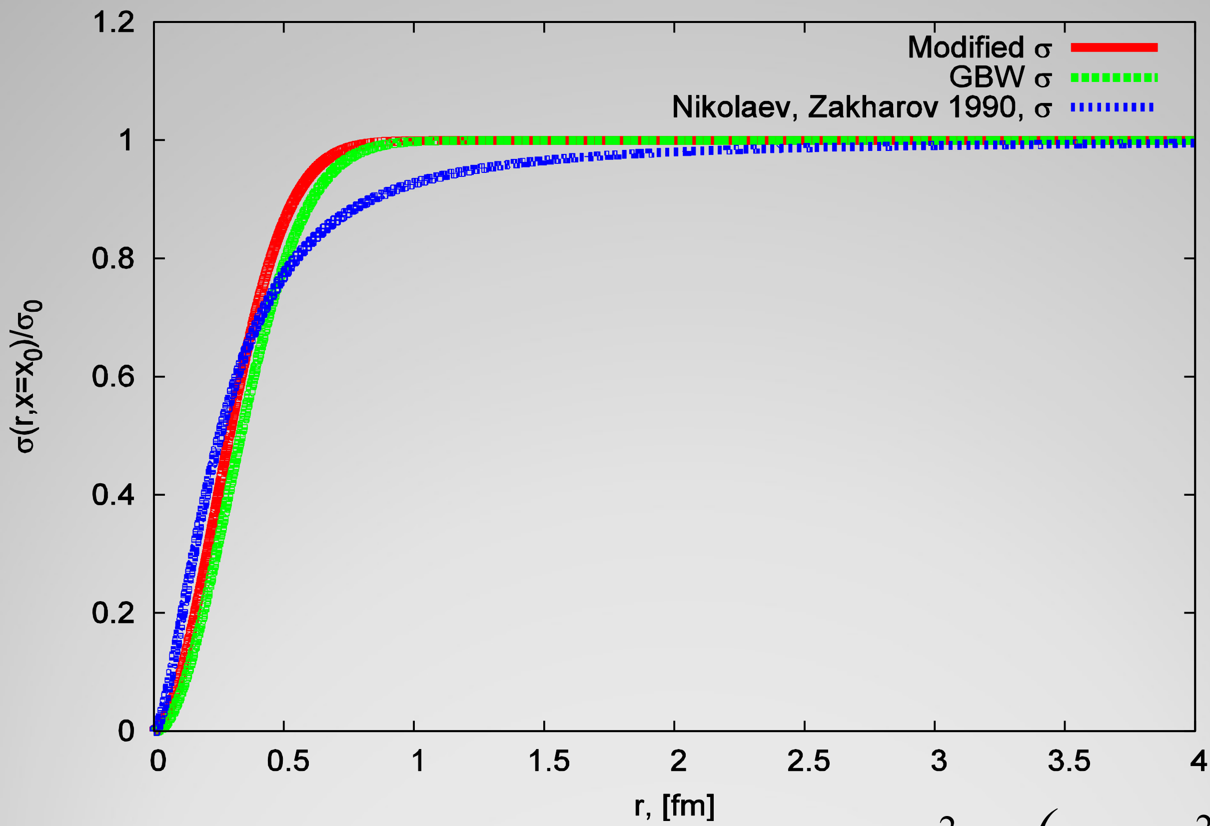
$$\rho_g(x=0,p_t)=\varphi_g(0,p_t)\sum_{n=2}(n-1)\sigma_n(s)=$$

$$\varphi_g(0,p_t)\left(gs^{\Delta}-\sigma_{nd}\right)$$



Modified σ
GBW σ
Albacete, Marquet σ
Nikolaev, Zakharov σ
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
σ(r, x=x0)/σ0
r, [fm]

Effective dipole cross section

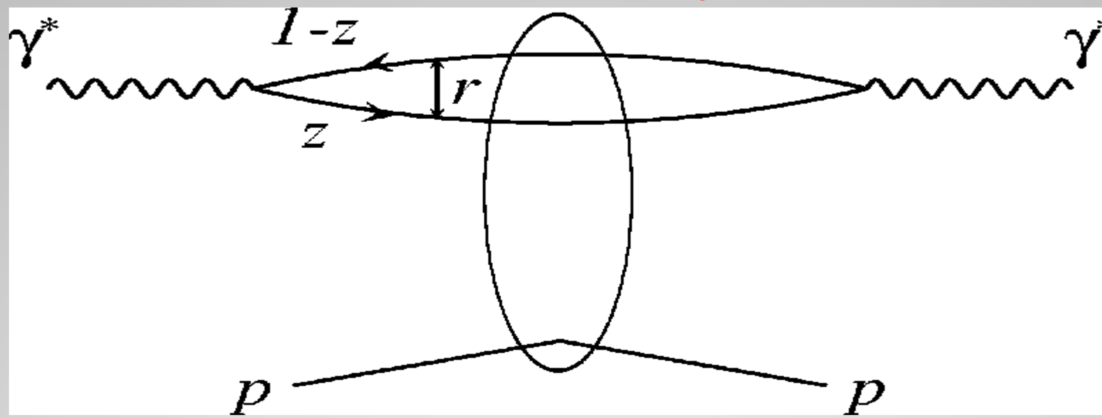


N.Nikolaev, B.Zakharov, Z.Phys.C49, 607 (1990)

Blue line corresponds to $\sigma_{dipole} = \sigma_0 \frac{r^2}{4R_0^2} \ln\left(1 + \frac{4R_0^2}{r^2}\right)$

K. Golec-Biernat, M Wuesthoff , Phys.Rev. D60, 114023 (1999); D59, 014017 (1998)

Saturation dynamics



$$\sigma_{dipole}^{GBW}(x,r) = \sigma_0 \left\{ 1 - \exp\left(-\frac{r^2}{4R_0^2} \right) \right\}$$

$R_0 = GeV^{-1}(x/x_0)^{\lambda/2}$ at $x < x_0$ we have $\sigma_{dipole} \approx \sigma_0$

Saturation becomes when $r \sim 2R_0$ It leads to $\sigma_T \sim \sigma_0$
when $QR_0 < 1$ or $Q < 1/R_0$

Effective dipole cross section and unintegrated gluon distribution

$$\sigma_{dipole}(x,r) = \frac{4\pi}{3}\int \frac{dk_t^2}{k_t^2}[1 - J_0(k_t, r)]\alpha_s xg(x,k_t)$$

Here α_s is the QCD running constant, J_0 is the Bessel function of the zero order.

Structure of an event

- Multiple parton-parton interactions